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Regulatory Uncertainty and the Natural Gas Industry in the US

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Abstract

The United States is in the midst of a natural gas boom, but it's unclear how long this high level of extraction is sustainable given the regulatory trajectory around carbon emissions and climate change. This paper examines how natural gas firms perceive regulatory uncertainty as measured by their capital expenditure. Using rig count data as a proxy for natural gas capital investment, I explore different ways to measure the perceived threat of state-level regulation and differing firm responses. I find strong evidence that regulatory uncertainty decreases the capital investments of firms, although I find that the effect of proposed regulation declines after about four months.

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1 Introduction

Natural gas has risen from a hydrocarbon side-product to a central and politically contentious element of US energy policy over the past 10 years. Since the discovery of hydraulic fracturing, natural gas output in the US has skyrocketed while costs declined. New geographical frontiers of gas drilling were surveyed and drilled, and America's energy infrastructure pivoted to consume the incoming flood of cheap natural gas. Natural gas was sold as the "bridge fuel" of a green future and the savior of US energy independence. In the midst of all this, much of America's coal industry was driven to bankruptcy.

At the same time, the specter of climate change has increasingly pressured national leaders to make commitments to reduce carbon emissions and chart a path towards a renewables-based economy. The supremacy of natural gas cannot last forever. The question is: is the "bridge fuel" ready to cross the bridge?

There is a large amount of uncertainty regarding issues of climate change and regulation. This paper attempts to measure some of the uncertainty around natural gas regulation and quantifies the responses of natural gas firms. In particular I examine the years 2000-2016, the time that hydraulic fracturing was entering popular use.

I measure natural gas firm responses through a set of panel data on state-level drilling rig counts. These data are a suitable proxy for the capital investment of natural gas firms and are a way to measure firm expectations of future profitability. To measure regulatory uncertainty, I use a database of state-level legislation and select for bills relating to natural gas. Instead of looking at when bills pass, I instead look at when bills are first proposed. I interpret periods of high legislative activity (around natural gas) as periods of high regulatory uncertainty.

I use a panel analysis to estimate the effect of increased legislative activity on variation in rig counts, and control for several key variables. I find that there is a strong and significant relationship between legislative activity and rig counts. A month after a bill relating to natural gas is proposed in a state legislature, the change in natural gas rigs in that state is reduced by an amount between 0.3 and 1. However, five months after a bill proposal, I find that states actually see an increase in rig activity. I hypothesize that this effect is due to suppressed drilling activity "catching up" after a sudden decrease in regulatory uncertainty when the legislative session ends.

2 Literature Review

Historically, natural gas has been a tightly regulated commodity. Until 1978, natural gas had been price-controlled by the federal government which created shortages in some regions and stunted the growth of the industry relative to oil (Joskow 2013). Following the oil shocks of the 1970s the government began to deregulate the natural gas market, allowing prices to rise to market value. During this process, there was a small bubble in natural gas markets as customers switched to gas from oil and back again during the 1979–1980 oil crisis. Regardless of this price fluctuation, Congress continued to deregulate wellhead prices and incentivize the growth of the pipeline transportation market. By the end of the 20th century the US natural gas market was well developed—setting the stage for its robust growth in the next decade.

It was known for many years that there were large natural gas deposits buried in shale in various places in the US, but it wasn't until the late 1990s that this gas became profitable to extract. Several technological developments came together—namely advancements in drilling technology and the invention of hydraulic fracturing—to make shale gas production a reality. Shale gas grew explosively: in Texas, shale gas production increased from almost nothing in 2000 to about five billion cubic feet per day in 2013. (Joskow 2013, p340) The natural gas boom has been strategically important to the United States in terms of energy independence and the balance of trade, but it has not been without controversy.

Joskow (2013) notes that many new drilling projects are taking place in states that did not have a regulatory framework or precedent for natural gas extraction. (Joskow 2013, p341) In addition, there has been public resistance to the idea of natural gas drilling. The resistance to natural gas is in response to both concerns about the safety of hydraulic fracturing (or "fracking"), and concerns about the global climate change trajectory.

Already, the natural gas boom is coming up against obstacles. Blohm et al. (2012) estimates the how existing policies, regulations, and land use impacted access to natural gas in the Marcellus shale region in New York and Pennsylvania. While estimates of "technically recoverable reserves" of natural gas ranged from 141 and 489 trillion cubic feet, about 48% of those reserves were deemed inaccessible for various reasons. The amount of inaccessible reserves has most likely increased since then—given that New York banned fracking entirely in 2014.

The growth of inaccessible reserves has necessitated an industry response. A rapid supply-side expansion combined with massive pressure to regulate have resulted in a shaky equilibrium. Gas extraction is a capital intensive business with long time horizons, and may therefore be vulnerable to regulatory threat.

Engau and Hoffmann (2011) provide a broad overview of the literature around responses to regulatory uncertainty, especially relating to climate regulation. There are a variety of possible responses to regulatory uncertainty, which have varying applicability to the natural gas market. Some possible responses are very direct—simply involving a reduction in firm output—and some responses, like firm restructuring, are more difficult to measure.

Engau and Hoffman use a survey sent to firm leaders, asking about uncertainty and firm responses. They argue that the oil and gas industry is less likely (relative to other industries) to pursue adaptation strategies in response to uncertainty surrounding climate regulation. This is probably because carbon emission is so fundamental to what the oil and gas industry does, and adaptation is not really a possibility. Regardless, the paper predicts that more regulatory uncertainty will induce a larger firm response.

In renewable energy generation markets, Fabrizio (2013) finds that energy firms invested less in states that were perceived to have a high "regulatory instability." Fabrizio measures regulatory instability by looking at the history of state legislatures, and whether they had flip-flopped on key regulatory issues. When states had a history of passing and repealing legislation relating to renewable energy, investments were diminished.

Ritzenhofen and Spinler (2016) provides a theoretical basis for the relationship between regulatory uncertainty and the renewable energy generation industry. Investment behavior in anticipation of regime switch depends on the relative levels of profitability between the two regimes. When there is minimal difference between the profitability of two regimes, regulatory uncertainty only reduces investments. However, when regulatory uncertainty threatens to change a highly profitable industry into a less attractive one, investors increase investments to capture the benefits of the profitable regime while it still lasts.

Literature varies around how to measure regulatory uncertainty empirically. Fabrizio treats regulatory instability as a constant that varies between state legislatures but that is invariable over time. However, this is a limited way to measure regulatory uncertainty.

Baker, Bloom, and Davis (2015) are perhaps at the forefront of measuring policy uncertainty. Baker et al. create a synthetic measure of broad "economic policy uncertainty" through a combination of three components: (1) textual analysis of widely read newspapers, (2) expected dates of federal tax code changes from the Congressional Budget Office, and (3) dispersion in professional forecasts of key macro variables. Baker et al. show that this synthetic measure is correlated with real macroeconomic variables like growth and unemployment.

If regulatory uncertainty is treated as measure that can both change over time, and that may vary between industries and legislatures, the question of firm response gets more complex. Is the natural gas industry optimally responsive to regulatory threat? The oil industry appears to be optimally responsive to oil prices, which vary unpredicably over time just like regulation. Kellogg (2014) estimated how oil company investment was impacted by oil price volatility in

Texas and determined that the empirical response closely aligned with the optimal response predicted by theory. An increase in price volatility corresponded with a decrease in well drilling—basically a decrease in firm capital investment.

This pictured is complicated by expectations of future volatility. The firm response is dependent on how the firm conceptualizes volatility in the long-term. If volatility is believed to have a random walk behavior, the optimal response is different than if volatility is believed to have a mean-reverting behavior. When mean-reverting assumptions are applied, Kellogg finds that firms will optimally respond less strongly to changes in volatility. (Kellogg 2014, p1723) To generalize this, Kellogg finds that business threats that are expected to be short-term incur a smaller response. Business threats that are expected to hang around for a while incur a larger response.

Schuwerk and Sussams (2016) provide a perspective for what this might mean in terms of regulatory uncertainty. Looking at how the coal industry has been impacted by climate regulation, They argue that coal firm expectations vastly underestimated regulatory risk. Coal companies underestimated risk by using assuming "business as usual" forecasts for coal demand, ignoring ongoing development of a carbon budget plan for the United States. Regulatory uncertainty was underestimated because firms failed to see a larger regulatory trajectory, "mistaking the forest for the trees." Observed coal demand fell well below industry expectations when a number of key environmental regulations were installed by the EPA, driving some firms to bankruptcy.

This paper attempts to expand existing literature on supply-side reactions to regulatory uncertainty by allowing uncertainty to vary over time and space, and by focusing specifically on natural gas. I take inspiration from Kellogg's (2014) modelling of volatility expectations, and attempt to apply these findings to regulatory uncertainty while acknowledging some differences between price volatility and regulatory uncertainty.

3 Institutional Setting

3.1 Natural Gas

3.1.1 Production

The production of natural gas, like oil, is an industry with very high fixed costs. Firms may spend months and up to 10 million dollars on a well before any returns are seen. (Hiller 2016) However once a well is drilled and the wellhead is installed properly, the investment will usually produce natural gas for the next decade or so. It is extremely cheap to maintain a well once it is producing, and difficult to increase production in an already-drilled well. Because of this, Kellogg finds that firms do not alter production rates or delay production in response to price changes. The decision to produce oil or to wait is made it at the start of the drilling process, which Kellogg models as a fully irreversible investment. (Kellogg 2014, Ponce and Neumann 2014 p10)

There is huge variation in natural gas withdrawals across states. This is largely due to the geological distribution of accessible natural gas deposits. The Marcellus shale formation sits below Pennsylvania and New York, however political backlash has prevented New York from exploiting or even measuring its deposits. The deposits run southwest across the US, pooling thickly around Texas and reaching into Louisiana and Oklahoma. In the west, Wyoming draws a lot of gas from the Green River Basin located in the southwest corner of the state. In the north, Alaska extracts large volume of natural gas as a byproduct of oil production. However, a lot of Alaskan natural gas does not make it to market on account of logistical costs. Added together, these states make up more than half of US natural gas production. (EIA)

The drilling process can vary widely in costs and time, depending on the geological and regulatory aspects of the site. First, the area is surveyed and land rights are purchased. This process can take around six months. Mapping and staking-out the well pad can take another month or two. Once this is complete, drilling can begin.

The first stage of drilling just goes below the water table, and a cement casing is laid in the hole to separate the gas that comes up from the local aquifer. (This well casing is not always failsafe and is one cause of concern for regulation.) Then, the well is drilled far deeper to reach the natural gas deposits deep in the earth. It takes about one month to get this far with drilling. For conventional wells, this is largely the extent of the process. Once the deeper, secondary drilling process is finished, natural gas will flow up the well and be collected by the wellhead for the next 1 to 30 years.

Conventional drilling techniques are usually used on sandstone or limestone formations, where the natural gas is pooled together in large quantities. The well does not need to open a very large surface area underground because natural gas will just naturally flow up from the large pool. Unconventional drilling is usually used on shale formations, where the gas is spread out into many tiny deposits across many layers of shale.

Unconventional drilling has powered the recent natural gas boom through its more intensive drilling process. Once the well is dug deep enough into a shale formation, the drill is turned sideways and bores outward for a mile or more. This horizontal drilling increases the amount of natural gas pockets that the well can pull from, but it takes another two months to complete after the vertical drilling is done.

After all drilling is finished, a natural gas firm may choose to use hydraulic fracturing on a well. First, small explosions are set off deep in the shale, exposing more of the rock to the well and perforating it. Then, 2 to 9 million gallons of chemicals, sand, and water and pumped into the well at very high pressures. This pressurized "fracking fluid" fractures the shale exposed to the well, forcing open small pockets of natural gas sealed within the rock formation. The fracking fluid is another concern that has spurred state regulation, especially because the chemical contents of fracking fluid are proprietary and confidential. The whole fracking process only takes about a week, and then the well is ready to start producing. The combination of horizontal drilling and fracking can double the costs of well digging, but it can also double or quadruple the amount of gas produced which makes fracking well worth it for producers. (Bezruchenko 2015, Investopedia, Shalefield Stories)

Recently, there has been interest in the practice of “refracking,” or fracking a well that has been in production for several years. Some wells that seemed like they were running dry have seen a massive boost in production after a secondary round of the fracking process. However, results are inconsistent, and the technology is underdeveloped. (Moser 2015) Refracking may be an emerging way for natural gas companies to vary well production in response to external conditions, but it has not achieved widespread use yet.

Baker Hughes, a drilling technology company, publishes a weekly count of all the oil and gas rigs that are active across the country. For Baker Hughes, any rig equipment that is in motion and drilling is counted as “active,” while equipment that is in transit or resting is “inactive.”

Within the context of the drilling timeline described above, rigs are marked active after the plot has had about 6 months of planning. Once a well starts getting drilled, the rig will remain active for 1-3 months depending on the type of extraction used. Then, the rig will go inactive while the well produces gas, for 1 to 30 years.

Viewed on the macro level, the most striking thing about the rig count data is that rig counts have drastically declined in recent decades. (See Figure 1) The annual change in rig counts has been negative since 2011. (Bezruchenko 2015) However, this picture is complicated by the massive recorded increase in production output. This growing disparity can be explained by an increase in productivity, mainly brought about by fracking.

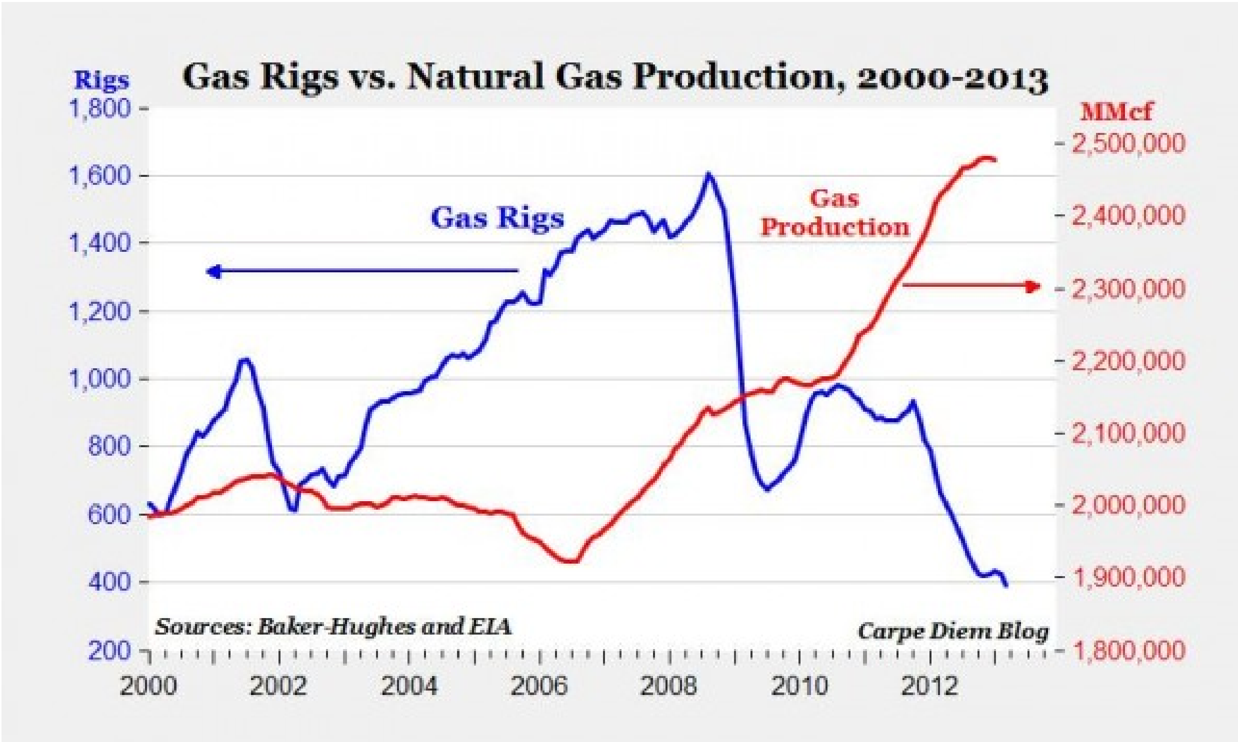

Figure 1: Gas rig counts vs. natural gas production. Source: Perry (2013)

It's clear, then, that a rig count in 2000 will not mean the same thing to an oil firm as a rig count in 2014. Because the productivity of rigs (and drilling costs) are constantly changing, the number of rigs is not an easily comparable measure of capital expenditure from natural gas firms.

On the monthly or weekly margin, however, rig counts provide useful information about capital investment. The decision to start drilling a well is based on the expected profit from the well. The decision can be delayed or expedited depending on expectations of the various costs and revenues associated with natural gas.

In a paper modelling oil drilling, Kellogg (2014) uses a simple model based on drilling costs and gas prices. Regulation (and regulatory threat) enter the model through drilling costs, via multiple mechanisms. Procedural regulations can increase compliance costs and tax regulations directly raise prices of factor inputs.

I assume natural gas firms are price-takers in this paper, which is a simplification of real market dynamics. Kusnetz (2011) estimates that there were roughly 14,000 oil-and-gas companies in 2009 drilling in the US, many of them small businesses. The multinational drillers have name recognition and some power over the market, with the 10 biggest drillers accounting for one-third of all production. Half of domestic natural gas can be traced back to just 40 of the US's biggest natural gas firms. However, the highly commodified nature of natural gas and the presence of robust regional utility markets preclude most concerns about price manipulation.

3.1.2 Consumption

After the gas is extracted from the well, there are more steps before it can be sold to consumers or manufacturers. The raw gas must be processed and refined, and it must be transported to market. Transportation of natural gas has emerged as a political hot topic, because of environmental concerns over pipelines. Natural gas can be transported in pipelines, pressurized in trucks, or cooled and liquified for extended trips.

Pipelines are the most cost efficient form of transportation but as it stands, the current infrastructure is not well equipped to deal with the large volumes of gas produced. The construction of additional pipeline infrastructure has high marginal returns, and is being pushed aggressively by the industry.

Regulation (and regulatory threat) around transportation of natural gas could certainly affect drilling decisions. The decision to approve a natural gas pipeline could stand to reduce distribution costs and make drilling more profitable. However, projects in involving infrastructure often cross state boundaries and affect huge geographical areas. These projects are overseen at a federal level, and involve extensive government/firm cooperation. Additionally, these projects function on a time scale of decades rather than months. For these reasons, I assume that my analysis of state-level regulatory uncertainty is unaffected by issues involving transportation of natural gas.

Finally, the gas works its way through the distribution system to the customer. Natural gas is purchased by both households and firms for three primary purposes: heating, energy generation, and transportation. There are readily available alternatives for all three of these applications, making demand for natural gas pretty elastic. There are some infrastructure costs associated with switching to natural gas, but natural gas prices have been so low that many customers are making the switch. (Kusnetz 2011)

Demand for natural gas is highly seasonal, peaking in the winter for heating. Despite this, gas prices and production don't seem to display seasonal patterns. (Production tends to decrease for the month of February, but this is a small effect.) This is made possible by natural gas storage facilities, which pump large quantities of gas into caverns underground in the summer and withdraw them in the winter. The gas in storage is separated into base (cushion) gas, which is needed to maintain adequate reservoir pressures, and working (top storage) gas, which gets taken in and out.

The storage volume of working gas in the US usually peaks at about 3.5 trillion cubic feet in October, and gets withdrawn down to 1 trillion by March. To give these numbers context, monthly natural gas production in US varied between 2 trillion in 2007 to 2.8 trillion in 2016. (EIA)

3.2 Regulatory Uncertainty

The study of regulatory uncertainty is complicated by the fact that defining regulatory uncertainty is almost as difficult as quantifying it. Regulatory uncertainty is an intangible force that can lock up markets and prevent capital investment. Because regulation can impact markets in so many different and indirect ways, the uncertainty preceding a regulation can be based around uncertainty of a regulation's impact *as well as* the uncertainty around the regulation's approval.

Baker, Bloom, and Davis (2015) make a good effort to measure macro-level policy uncertainty as it changes over time. The authors use multiple indicators to derive their measure of "Economic Policy Uncertainty" (or EPU), but the one relevant to this analysis is an index of search results from 10 large newspapers across the country. The more often that newspapers use certain keywords involving public policy, the higher the measure of EPU gets. The authors then show that this indicator has a significant relationship to real macroeconomic variables. An increase in EPU precedes a decline in economic growth and employment over a period of months. The wide variety of keywords that Baker et al. use capture a diversity of public policy issues, which is too broad for this analysis. Instead of using the same measure of EPU, I take inspiration from the approach but apply different keywords to a different dataset.

Instead of analyzing the text of newspapers, I analyze the text of state legislature documents. Specifically, I look at the quantities and dates of proposed bills that mention the words "natural gas." This is an imperfect measure of regulatory uncertainty, but captures some amount of state regulatory activity that precedes actual regulations, in line with Baker et al.'s textual analysis.

While I use the term "regulatory uncertainty," Baker et al. use "policy uncertainty." Furthermore, Schuwerk and Sussams (2016) measure "regulatory risk" and Fabrizio (2013) talks about uncertainty in relation to "regulatory instability." Because of the diversity of vocabulary used on this subject, some specification might be necessary. Although these terms are closely related, they measure slightly different things. I see *regulatory* uncertainty as a subset of *policy* uncertainty. Policy can consist of expenditures, taxes, and other things that affect businesses, but regulation is the most direct application of policy from a firm's perspective.

The three terms "uncertainty," "instability", and "risk" all describe situations where there are multiple outcomes that could effect firms. I use "uncertainty," because sounds more neutral, and could describe positive outcomes as well as negative outcomes. Knight (1921) attempts to distinguish between risk and uncertainty even more concretely by saying that "risk applies to situations where we do not know the outcome of a given situation, but can accurately measure the odds" and that uncertainty "applies to situations where we cannot know all the information we need in order to set accurate odds in the first place." (Dizikes 2010) Finally, I see instability as a sub-type of risk.

Separating the three terms is somewhat futile, considering the crudeness of my variable. Other academic literature is not entirely consistent about these definitions. However, I hope that it will clarify the framework of my model and possibly contextualize other research that has been done in this area.

When discussing regulatory uncertainty, sometimes it can become unclear how strong the effects of regulation actually are. Because there are different ways that regulation can impact natural gas firms, and the mechanisms can be direct or indirect, the issue can seem very abstract. For a specific example of regulation's powerful impact on extractive industries, I point to Schuwerk and Sussam's (2016) work on the coal industry. Schuwerk and Sussams chart the decline and bankruptcy of the coal industry since 2005 and argue that environmental regulation played a key role in the financial ruin of coal firms. The authors point to 7 key regulations implemented by the EPA "aimed to mitigate the detrimental environmental and human health consequences of coal burning." (p35) These regulations had a demand-side effect, which severely decreased price and quantity after 2011. The authors admit that it is difficult to prove the causality of these regulations on a macro scale, the authors posit that they had a sizable effect.

How does regulatory uncertainty vary over time? From the perspective of a natural gas firm, when is it safe to start drilling again? Empirically, this is difficult to measure accurately. After a bill is proposed in a state legistature, any number of things could happen: (1) the bill could pass, or (2) it could fail, or most likely, (3) it could get tied up committee proceedings while clearing the field for other regulatory legislature to get pushed through. It isn't clear how long and how hard any state legislature will push for regulating any given industry. However, through looking at how the natural gas industry responds to legislative threats, one can get a picture of the industry's own model for evaluating regulatory threats over time.

The industry's own expectations for regulation aren't always borne out in reality. Looking at how the coal industry has been impacted by climate regulation, Schuwerk and Sussams (2016) argue that coal firm expectations vastly underestimated regulatory risk. Coal companies underestimated risk by using assuming "business as usual" forecasts for coal demand, ignoring ongoing development of a carbon budget plan for the United States. Regulatory uncertainty was underestimated because firms failed to see a larger regulatory trajectory, "mistaking the forest for the trees."

When it comes to the nuts and bolts of state legislatures, they function very similarly to the US Congress. What complicates matters is that states vary on the details of this model. All state legislatures except Nebraska are bicameral, which means that they have an "upper house" and a "lower house," comparable to the House and the Senate.

Bills are introduced in one of the houses when the legislature is in session. A bill will have a "first reading," and then be referred to a committee. The committee will work on the bill. If a bill doesn't die in committee, it will finally (after a number of readings) be brought to the house for a vote. Once one house passes a bill, it must pass over to the other house and be passed there. Finally, once a bill has been approved in both houses, it must be signed by the governor. The governor has veto power, although it may be overridden by some majority of the members of each house.

In the dataset for this paper, only about 13% of the bills introduced have been signed and passed into law. Others have been lost at various points in the legislative process–being signed in one house but not the other, or simply dying in committee. Sometimes, a bill with the same name and substantially the same text as bill from a previous legislative session is introduced to a legislature, essentially reintroducing a bill for the current session. When reintroduced bills are treated as a unit, the success rate of bills increases to 18%.

It's also important to note that regulatory activity is highly seasonal. This is because most state legislatures come into session in mid-January, leading to a jump in bill proposals in February. States set the dates of their legislative sessions independently, so some states like Louisiana have legislative sessions in the summer. Texas, Montana, Nevada, and North Dakota are unique for only having a legislative session on odd-numbered years, leading to an increase in legislative activity in these years.

4 Data

4.1 Regulatory Uncertainty

In order to estimate regulatory uncertainty for a given state at a given time, I use the Open States database of state legislation. This database is updated by the Sunlight Foundation, who make a good effort to simplify differences across state legislatures and their online APIs. State legislatures vary significantly both procedurally and in record-keeping, but the basic path of a bill from introduction to signature is shared.

Using the search term "natural gas" on the Open States API returns 1348 bills in 50 different states, about 30% of which are reintroductions (bills with identical titles to previously introduced bills).

It can be extremely difficult to deduce the intent of a bill from the title. Some bills are forthright about their intent to restrict the growth of the natural gas industry, but others seem to merely address small procedural considerations around drilling. Some bills are crafted to seem innocuous in language while dramatically changing the industry playing field. Hiding the intent and implications of bills through bureaucratic and indirect language is a staple of politics, but can make research difficult. This problem is intensified by the sheer quantity of bills at hand.

For the purposes of this paper, I assume that the "average" bill is one that restricts the natural gas industry in consideration of environmental impacts. This is a large but not unfounded assumption. At a basic level, one of the roles of the state legislature is to regulate at the expense of industry and at the benefit of environmental public goods. The majority of bills are created in order to add *more* regulation on the natural gas industry, not to take regulation away. A close examination of some of the bills in the database seems to bear this out. Although not all bills could be examined, a random sampling of bills seems to assure the regulatory role of new state legislation. (See table in Appendix.)

A surprisingly large amount of bills deal with the consumer side of the natural gas industry: gas distributers, utilities, and electricity generators. These bills would indirectly affect the capital investment of natural gas drillers, although the effect would probably be smaller. These bills sometimes include subsidies of natural gas development, to ensure its supremacy over coal. However, of the bills that address natural gas drilling or pipelines directly, the language is almost exclusively negative.

It is also worth remembering that the bill data is meant to measure regulatory *uncertainty*, not just regulation. Any proposed bill related natural gas would raise the level of uncertainty while the bill is active in session. Uncertainty measures the variation in possible outcomes, but not explicitly if these outcomes are positive or negative. I treat the proposal of a bill on a certain date as a measure of increased regulatory uncertainty at the time that it was proposed.

There is a large amount of diversity in the regulatory regimes for each state. Some states have a high amount of regulatory activity, where others have none at all. New York stands out with 201 bills overall, and Pennsylvania is a distant second with 151. Regulatory activity peaks in 2013, and declines afterward. As regulations become successfully enacted, the need for additional regulation may decline. This might explain the declining number of bills, especially because New York enacted a fracking ban in 2014.

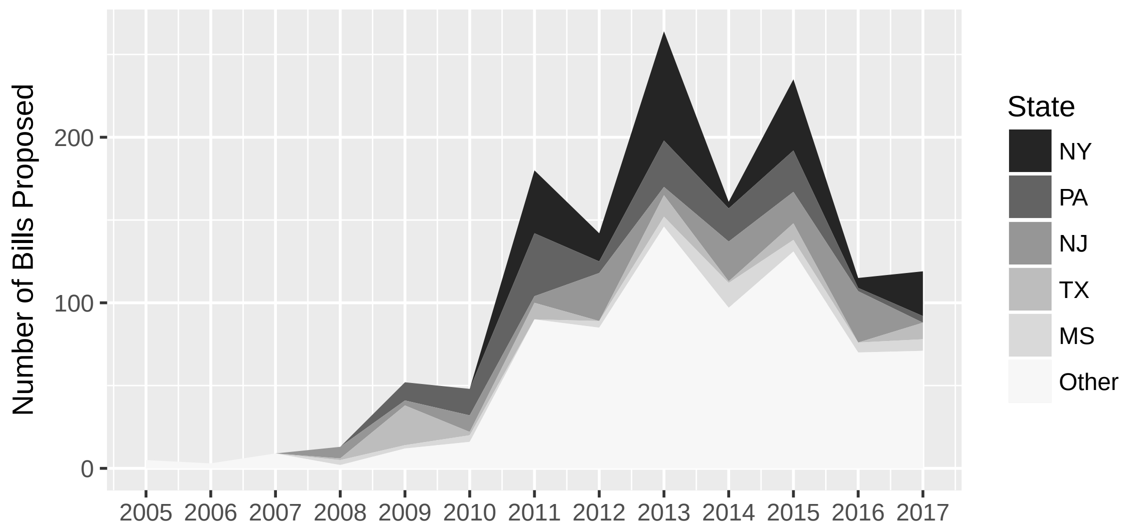

Figure 2: Proposed bills by year and state

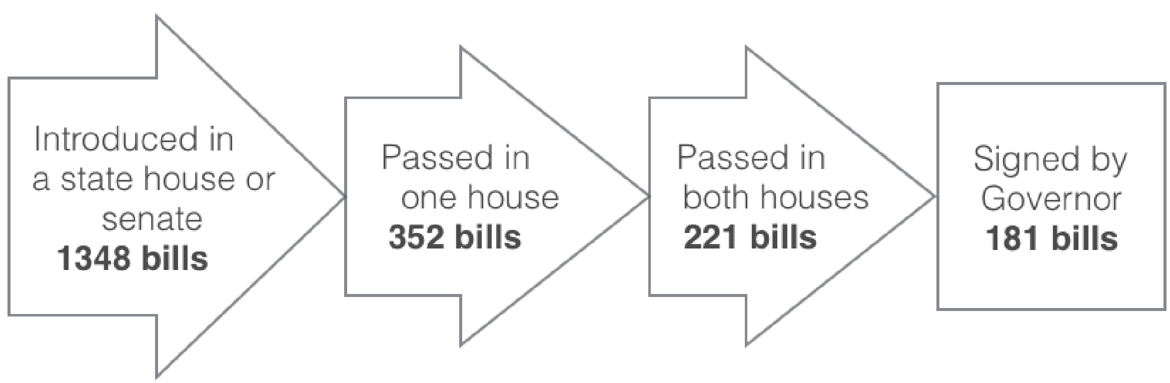

Figure 3: Bill counts by progress through legislature

4.2 Natural Gas

I use natural gas “rig counts” as a measure of industry’s capital investment over time. Since the decision to drill a rig is a form of capital investment, the number of actively drilled rigs is a good measure of aggregate capital investment by state.

Baker Hughes, a drilling technology firm, publishes weekly data on the number of active natural gas rigs by location and type. The number of rigs varies widely between states, which align with the relative well output of different states.

These panel data are recorded and aggregated in a number of different ways by Baker Hughes. One tally measures relative numbers of natural gas rigs and oil rigs in the country. Another divides rigs up geographically by state. Unfortunately, Baker Hughes does not provide long-run data that divide rigs by both type of fuel *and* state. The micro-data that do allow this type of specification only go back to 2011.

The decision to specify a specific drilling operation as "natural gas" or "oil" can be subjective in certain cases, as Baker Hughes notes. Because most wells output a mix of both hydrocarbons, the classification is solely based on the rig permit is issued by the state's permitting authority through the judgement of the rig operator.

Because of these difficulties, the rig count data that I use does not distinguish between oil and gas rigs. As a supplemental exploration I use the gas rig data that starts in 2011 and find similar results.

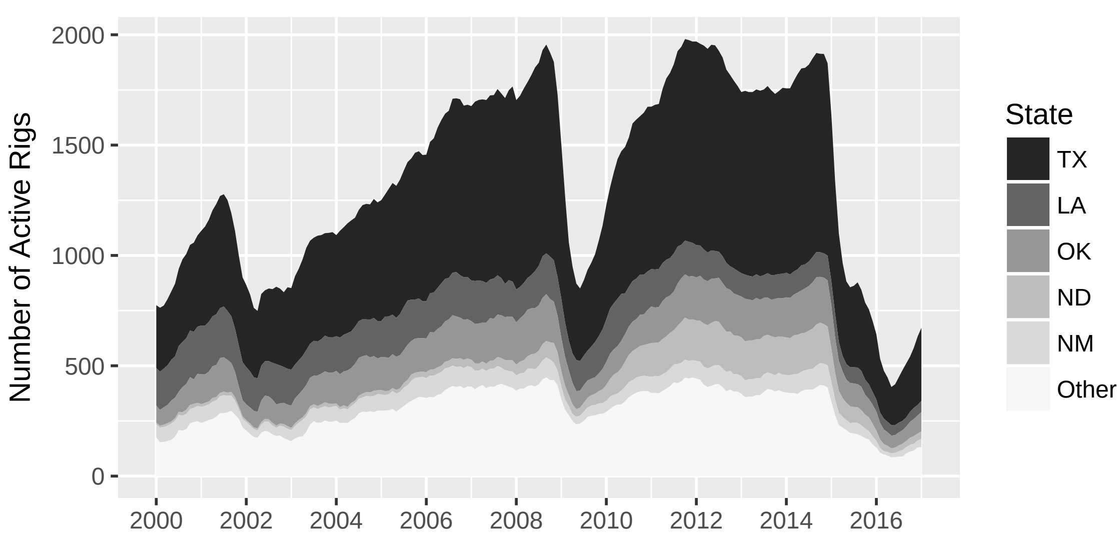

Figure 4: Active rigs by year and state

Baker Hughes speculates briefly on their FAQ page what factors might influence rig counts.

While "the strength and stability of energy prices" is the primary factor, they also list (1) technological improvements, (2) natural disasters, (3) seasonal weather and spending patterns, and (4) political environment as other major influencers of rig counts. In my analysis, I attempt to control for the other factors listed, in order to estimate how a particular facet of the "political environment" might influence rig counts.

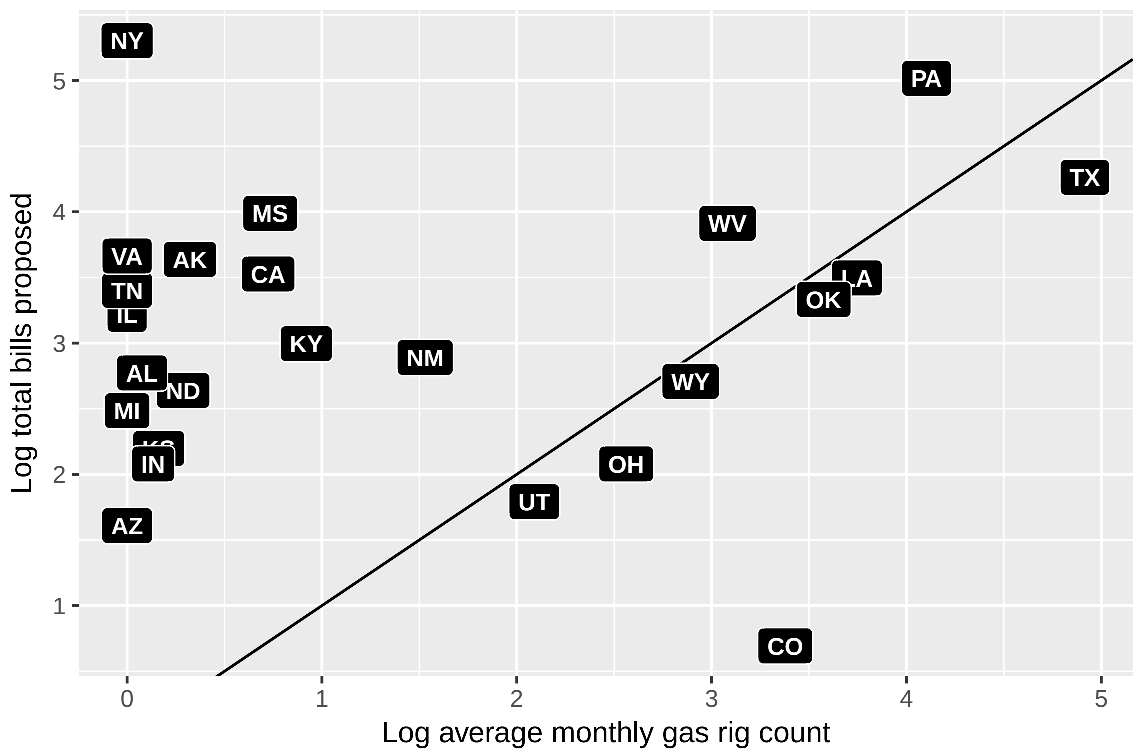

Figure 5: Average rigs vs bills proposed by state

Viewing rig data in relation to the bill data and removing the time dimension gives some idea of the relationship between the two datasets. New York is a very high regulator, but never actually drilled that many gas wells. Pennsylvania and Texas emerge as the two states essential to this analysis, since they are both high regulators and high drillers. This chart provides no evidence of causality, but does give a high-level perspective of the relative placement of various states.

In order to look at how rig counts are affected over time by regulatory uncertainty, I use *marginal* rig counts instead of absolute numbers. Specifically, I derive the *change in rig counts* *by month* for all states. Many states only tend to use one rig at the time, so the change in rig count will vary between 1 and -1. High-volume drillers like Texas use many rigs, and change in rigs varies from -150 to 50. Negative changes in rig counts seem to happen more quickly than positive changes, leading to higher negative changes in the distribution. This is visually evident from the saw-tooth shape of rig counts when graphed over time. (See Figure 4.)

In order to integrate bill data with rig data, I create a statistic of the number of bills proposed each month in each state and merge those monthly observations into the rig observations. Many monthly observations of bill activity are 0, meaning that the bill data are highly skewed to the left.

I also experiment with dividing bill data into two groups: "original bills" and "unoriginal bills." My bill dataset includes many bills that are reintroductions: bills that were not passed in previous legislative sessions and so are brought up for re-consideration by the legislature. By separating the reintroductions out, I can measure the effect of reintroductions independently from the effect of original bill proposals.

4.3 Price and Gas In Storage

As control variables, I pull data from the Energy Information Administration on both gas prices and gas in storage. The EIA is a government bureau that collects and archives a number of statistics relating to natural gas markets.

For gas prices, I use EIA data on futures prices. A future is financial contract to buy a given commodity at a certain price at some point in the future. Futures are used to "lock-in" prices for commodities like natural gas. Because of this property, markets are incentivized to value futures as the *expected price* of the commodity in the future.

When natural gas firms are making a decision to drill, they are not basing the decision on current prices. Instead, they base that decision on their expectation for future gas prices.

Futures, then, are ideal for my model which aims to predict drilling decisions. The time delay of futures also circumvents issues of simultaneity.

I use an EIA contract that is valued at the expected price of natural gas 1 month in the future. The prices are not discernably seasonal, but instead tend to fluctuate pretty randomly month-to-month. Gas prices look like they capture some macro-economic cyclical activity, and the variable appears to be a good control that captures a lot of exogenous context.

I assume the same price for every state in my model. Although gas prices do differ regionally, they differ by a set amount that should be equal to the cost of transportation. States that are far from natural gas resources have higher gas prices, but these prices are higher by a consistent amount over time.

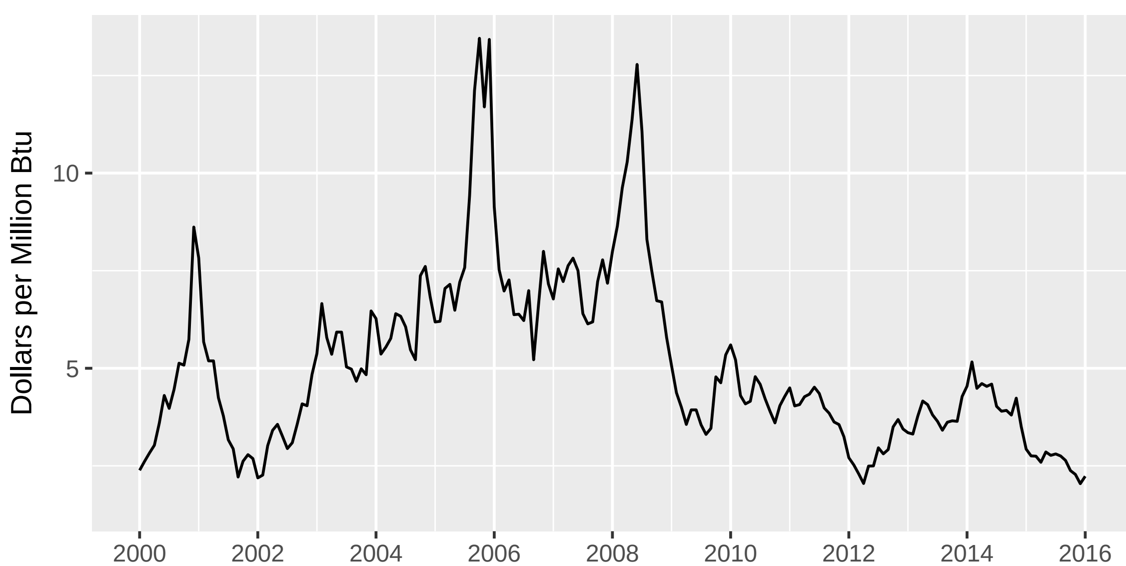

Figure 6: Price for Contract 1 natural gas futures

For storage, the EIA publishes a weekly tally of the amount of working gas in underground storage. The amount of gas in storage fluctuates on a seasonal basis, which is what evens out demand and keeps prices from fluctuating seasonally. The EIA changed their regional categorizations for gas storage in 2010, so I patch two EIA data sources together in order to get coverage for all the years studied.

I use nationally aggregated storage data instead of state-level data, because I assume that transportation costs are minimal for natural gas. The decision to drill for more gas might depend on how much gas is already in storage, but the distance between the driller and the gas in storage should be irrelevant to the decision to drill.

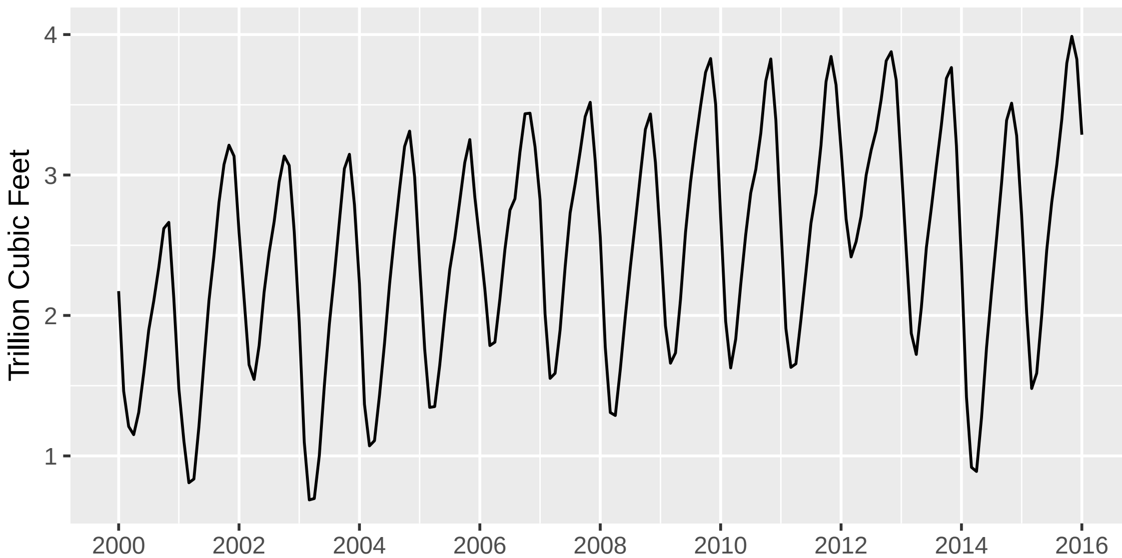

Figure 7: National working gas in underground storage

Table 1: Summary statistics

Statistic	N	Mean	St. Dev.	Min	Max
Rig count (oil and gas)	9,635	28.726	98.993	0.000	946.000
Rig count (gas only, post-2011)	1,007	26.755	48.472	1.000	350.333
Change in rig count	9,588	−0.011	4.904	−156.500	49.250
Change in rig count (gas only, post-2011)	943	−0.748	3.855	−29.200	19.750
Bills proposed in month T	9,635	0.129	0.807	0	22
Original bills proposed	9,635	0.090	0.522	0	10
Unoriginal bills proposed (reintroductions)	9,635	0.040	0.491	0	18
Gas in storage (Trillion Cubic Feet)	9,635	2.505	0.803	0.686	4.026
Price for 1-month future (per Million Btu)	9,635	4.932	2.264	1.812	13.455

5 Model

Because rig counts are a good way to observe the level of capital investment of natural gas companies, *change in* rig counts is a great way to observe investment *responses* to external stimuli. In this paper, I attempt to study the response of natural gas firms to regulatory uncertainty.

I quantify regulatory uncertainty as the number of bills proposed within a certain state during a certain month, and examine how the presence of those bills affects natural gas firms over time. An essential part of the strength of this model is the *randomness* of bill proposals. Although the decision to propose a bill is not a purely random treatment assigned by the state legislature, the exact date of a bill proposal *is* random. The difference between filing a bill on June 30th and July 1st is mostly unsubstantial for a state legislature, but the random variation in filing times allows my model to estimate the effects of these bills.

My first model is the simplest. I estimate the effects of bills proposed in t-1 (or last month) on the change in rig count in the current month. The dependent variable (change in rig count) is also affected my control variables: expected prices, gas in storage, time trends, and month fixed effects. In this equation, $ExpectedPrice_t$ refers to the expectation of what the price will be in t+1, which is observed in time t.

(1) $ChangeInRigCount_{state,t} = \beta_0 + \beta_1 BillsProposed_{state,t-1} + \beta_2 ExpectedPrice_t + \beta_3 GasInStorage_t + \beta_4 TimeTrend + Month\beta_{FE} + \epsilon_{state,t}$

In my second model, I have 6 different bill variables, to measure the lagged effects of regulatory uncertainty. When a bill is proposed in time t, the effect (if any) will show up in β_1 a month later. A month after that, the bill is two months old and the effect (if any) will show up in β_2, and so on. This lagged estimator effect continues 6 months back from the date of the rig count observation.

(2) $ChangeInRigCount_{state,t} = \beta_0 + \sum_{\mathbf{n=1}}^{\mathbf{6}} \beta_n BillsProposed_{state,t-n} + \beta_7 ExpectedPrice_t +$

$\beta_8 GasInStorage_t + \beta_9 TimeTrend + Month\beta_{FE} + \epsilon_{state,t}$

I also include five more regressions to test the robustness of my results. First, I include state fixed effects. Since states vary dramatically in rig activity, controlling for state fixed effects allows the dependent variable to shift up or down depending on where it is being observed geographically.

(3) $ChangeInRigCount_{state,t} = \beta_0 + \sum_{n=1}^{6} \beta_n BillsProposed_{state,t-n} + \beta_7 ExpectedPrice_t +$
$\beta_8 GasInStorage_t + \beta_9 TimeTrend + Month\beta_{FE} + \mathbf{State}\beta_{\mathbf{FE}} + \epsilon_{state,t}$

Then I experiment with my gas-specific rig data. The Baker Hughes data that spans my entire time range (2000-2016) lumps together both oil and natural gas rigs. This is inconvenient, because I can't observe the difference between gas rig responses and oil rig responses. As an alternative, Baker Hughs offers natural-gas-specific rig counts with observations from 2011-2016. The gas-specific data cuts down on the number of observations because of the limited time span. However, I run a regression with these data simply to compare results. I experiment with both one-month and one-to-six-month lag effects.

(4) $ChangeIn\mathbf{Gas}RigCount_{state,t} = \beta_0 + \beta_1 BillsProposed_{state,t-1} + \beta_2 ExpectedPrice_t +$
$\beta_3 GasInStorage_t + \beta_4 TimeTrend + Month\beta_{FE} + \epsilon_{state,t}$

(5) $ChangeIn\mathbf{Gas}RigCount_{state,t} = \beta_0 + \sum_{n=1}^{6} \beta_n BillsProposed_{state,t-n} + \beta_7 ExpectedPrice_t +$
$\beta_8 GasInStorage_t + \beta_9 TimeTrend + Month\beta_{FE} + \epsilon_{state,t}$

Finally, I experiment with separating my bill dataset. I hypothesize that original bills are more powerful than reintroduced bills, since they are more unexpected than reintroduced bills. I separate original bills from unoriginal bills and measure the effects of the two types separately. I experiment with both one-month and one-to-six-month lag effects.

(6) $ChangeInRigCount_{state,t} = \beta_0 + \beta_1 \mathbf{Original}BillsProposed_{state,t-1} + \beta_2 \mathbf{Unoriginal}BillsProposed_{state}$
$\beta_3 ExpectedPrice_t + \beta_4 GasInStorage_t + \beta_5 TimeTrend + Month\beta_{FE} + \epsilon_{state,t}$

(7) $ChangeInRigCount_{state,t} = \beta_0 + \sum_{n=1}^{6} \beta_n \mathbf{Original}BillsProposed_{state,t-n} +$

$$\sum_{n=1}^{6} \beta_{n+6} \textbf{Unoriginal} BillsProposed_{state,t-n} + \beta_{13} ExpectedPrice_t + \beta_{14} GasInStorage_t + \beta_{15} TimeTrend + Month\beta_{FE} + \epsilon_{state,t}$$

6 Results

My first regression provides strong evidence that regulatory uncertainty has a measurable effect on natural gas investment activity. (Table 2) An additional bill proposed in the previous time period decreases the change in rig count by almost 0.5 rigs, which means that 2 bills in a month will lead to a state taking one more rig offline than they would otherwise do. Surprisingly, the regulatory effect is larger than the price effect.

The 6-month model complicates this picture. One to two months out, the effect of regulatory uncertainty is measurably negative. At three to four months, the effect becomes insignificant. However, at five months out, the effect becomes measurably positive. Why would bills being proposed five months ago positively affect current rig counts?

I hypothesize that this effect could be due to the ending of legislative sessions. Most legislative sessions last between 40 and 120 days. After two months, some of the legislative sessions in my dataset will have ended. At 5 months, a larger group of states will have retired their session. Only the full-time legislatures would potentially circumvent this effect. Once a legislative session has ended, the bills that were proposed but not passed in that session are killed. They must be reintroduced to be brought back into play.

I hypothesize that legislative session timing could be leading to the positive effect of bills proposed five months ago on rig counts. Rigs that had been suppressed by regulatory uncertainty over the past five months are freed, and they all spring into action at once.

Although month dummies are not included in the tables, they are highly significant and positive for April through September. When I also add in state dummies in model 3, none of them are significant, and they have a minimal effect on the other coefficients.

Table 2: Models 1, 2, and 3

	Dependent variable:		
	changeRigCount		
	Model1	Model2	Model3
Bills T-1	-0.487^{***}	-0.417^{***}	-0.435^{***}
	(0.066)	(0.073)	(0.074)
Bills T-2		-0.218^{***}	-0.230^{***}
		(0.077)	(0.077)
Bills T-3		-0.095	-0.106
		(0.077)	(0.077)
Bills T-4		0.052	0.041
		(0.077)	(0.077)
Bills T-5		0.242^{***}	0.230^{***}
		(0.077)	(0.077)
Bills T-6		0.054	0.036
		(0.073)	(0.074)
Futures price	0.118^{***}	0.127^{***}	0.125^{***}
	(0.024)	(0.025)	(0.026)
Gas in storage	-0.066	-0.052	-0.061
	(0.172)	(0.174)	(0.175)
Time trend	-0.010	-0.009	-0.006
	(0.014)	(0.015)	(0.015)
Constant	19.840	16.300	11.685
	(28.852)	(30.408)	(30.607)
State dummies	✗	✗	Yes
Month dummies	Yes	Yes	Yes
Observations	9,588	9,353	9,353
Adjusted R^2	0.014	0.016	0.012
Residual Std. Error	4.869 (df = 9572)	4.909 (df = 9332)	4.919 (df = 9286)

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

The regression with the data on gas-only rigs has a severely limited number of observations, but the results are surprisingly similar. (Table 3) Regulatory uncertainty still seems to have a measurable and a large effect on rig counts. While the short-term effect of bill proposals is negative, the positive effect after five months still applies.

When only observing gas rigs, the estimated effect of gas prices is understandably a lot higher. Additionally, my gas storage and time trend coefficients become larger and more significant. This increased specificity of gas-only rigs benefits the R-Squared of my model, which increases from 0.016 to 0.069.

Surprisingly, month dummies become insignificant with gas-rig-only data. Perhaps this is because they were capturing a seasonality in oil rig counts that isn't present in the gas-only data. The estimated constant also shifts dramatically, which is probably balanced out through the new predictive power of the three control coefficients.

When I separate original and unoriginal bills, I find that original bills have a much stronger effect on rig counts. (Table 4) I hypothesize that original bills are a stronger representation of regulatory uncertainty, because they can't be anticipated in the same way that reintroduced bills can.

Table 3: Models 4 and 5 (Gas rigs only)

	Dependent variable:	
	changeRigCountGas	
	Model4	Model5
Bills T-1	-0.302^{***}	-0.290^{**}
	(0.109)	(0.114)
Bills T-2		-0.124
		(0.115)
Bills T-3		-0.069
		(0.115)
Bills T-4		-0.044
		(0.113)
Bills T-5		0.346^{***}
		(0.110)
Bills T-6		-0.058
		(0.107)
Futures price	1.470^{***}	1.496^{***}
	(0.346)	(0.346)
Gas in storage	1.114^{*}	1.135^{*}
	(0.672)	(0.671)
Time trend	0.444^{***}	0.450^{***}
	(0.095)	(0.095)
Constant	-902.290^{***}	-915.321^{***}
	(193.606)	(193.160)
State dummies	✗	✗
Month dummies	Yes	Yes
Observations	943	943
Adjusted R^2	0.063	0.069
Residual Std. Error	3.732 (df = 927)	3.719 (df = 922)
Note:		*p<0.1; **p<0.05; ***p<0.01

Table 4: Models 6 and 7 (Filtered bill data)

	Dependent variable:	
	changeRigCount	
	Model6	Model7
Original Bills T-1	-1.065^{***}	-0.949^{***}
	(0.103)	(0.107)
Original Bills T-2		-0.505^{***}
		(0.109)
Original Bills T-3		-0.271^{**}
		(0.109)
Original Bills T-4		0.033
		(0.109)
Original Bills T-5		0.378^{***}
		(0.109)
Original Bills T-6		0.137
		(0.107)
Unoriginal Bills T-1	0.190^{*}	0.192
	(0.114)	(0.127)
Unoriginal Bills T-2		0.080
		(0.134)
Unoriginal Bills T-3		0.017
		(0.136)
Unoriginal Bills T-4		0.072
		(0.136)
Unoriginal Bills T-5		0.010
		(0.134)
Unoriginal Bills T-6		-0.007
		(0.127)
Futures price	0.114^{***}	0.120^{***}
	(0.024)	(0.025)
Gas in storage	-0.094	-0.098
	(0.172)	(0.174)
Time trend	-0.005	0.0005
	(0.014)	(0.015)
Constant	8.275	-1.874
	(28.818)	(30.587)
State dummies	✗	✗
Month dummies	Yes	Yes
Observations	9,588	9,353
Adjusted R^2	0.020	0.024
Residual Std. Error	4.856 (df = 9571)	4.891 (df = 9326)
Note:		*p<0.1; **p<0.05; ***p<0.01

7 Conclusion

This paper provides a small but intriguing window into the “mind” of a natural gas firm. Firms are constantly evaluating the outside world, calculating risks, and responding in order for their own self preservation. By observing how firms respond to certain inputs, economists can learn a lot about the nature and context of those inputs.

This paper attempts to measure the firm response to the somewhat unquantifiable idea of “regulatory uncertainty” Although regulatory uncertainty is less tangible than other things that natural gas firms might respond to, its “realness” is confirmed by the fact that firms seem to respond to it so strongly.

However, just because firms respond strongly to regulatory uncertainty does not mean that their response is efficient or well calibrated. The natural gas industry is at a crossroads at this point in time, and the industry’s place in relationship to developing climate policies is uncertain. Although I observe a measurable response from natural gas firms in response to state legislative behavior, it is difficult to understand or completely quantify what these firms are responding *to* or how they *should* respond.

I find the fact that the response to legislation disappears in two months somewhat concerning. These results seem to say that natural gas firms are responding to regulatory uncertainty in the short term, but aren’t looking at the larger regulatory trajectory of natural gas in the US. As international negotiation around climate change continues, perhaps the situation will change.

Aside from waiting for more data, there are a number of additional directions I hope to take this project. Firstly, I want to dig deeper into the falloff in effect significance that happens after two months. I hypothesize that these effects are caused by the behavior of legislative sessions. To investigate this, I hope to incorporate session data into my model in various ways. I also hope to go beyond state legislatures, and perhaps model regulatory uncertainty with the state executive branch, or through another more exotic proxy.

A better understanding of the uncertainties on the horizon will allow firms and policymakers to better prepare and adapt for the future. The stakes of international energy policy are high, and it would be best that our society–with all its vices and all its virtues–could choose the most socially optimal path for its own posterity.

8 Appendix

Table 5: A random sample of 15 state bills from the database

Bill Title	Explanation
Prohibits treatment, discharge, disposal, or storage of wastewater, wastewater solids, sludge, drill cuttings or other byproducts from natural gas exploration or production using hydraulic fracturing.	**This New Jersey bill was introduced in both houses in January 2012. This bill aggressively regulates a byproduct of fracking, making fracking very difficult. The bill was vetoed twice and then reintroduced after a slight retweaking, where it still sits in committee.**
Natural gas public utilities; rates and charges.	This Kansas House bill was introduced in 2011 to change the way that natural gas utilities changed their pricing. The indirect effect on natural gas extraction was probably small. The bill never made it past committee.

Bill Title	Explanation
Natural gas fueling stations; tax credit for certain owners of stations that are open to the public.	**A 50% reduction in taxes associated with fueling stations, for natural gas stations. This bill died in a Virginia commitee in 2015.**
Establishing a committee to study the safe delivery of oil and gas, including natural gas and propane, throughout the state of New Hampshire and making a technical correction in the oil pipeline facility spill response plan.	This bill was signed into New Hampshire law in August 2014. The committee released its final report in 2015, making some recommendations for the clarification and intensification of the existing regulatory structure.
Resolve, to establish a moratorium on the assessment of large volume consumers by gas utilities and to evaluate cost-effective natural gas conservation and efficiency improvements for large volume consumers	**A 2015 bill to prevent large (industrial) gas consumers from benefiting from Maine's "natural gas conservation fund." The bill was ultimately vetoed.**
A bill for an Act to provide for a legislative management study of reduction of the flaring of natural gas.	Flaring gas is a practice used by the natural gas industry to ease well pressures, but it pollutes the air. This North Dakota bill would have looked into reducing gas flaring. The bill passed the Senate, but failed in the House in 2011.

Bill Title	Explanation
Relating to a study regarding the odorization of natural gas transported in gathering and transmission lines located in populated areas.	**This bill would look into creating more regulations for natural gas sold to consumers. This is a consumer safety issue, but the bill died in a Texas House committee in 2011.**
A Resolution supporting continued and increased development and delivery of oil derived from North American oil reserves to American refineries and urging the President and Congress of the United States to support the continued and increased production and use of American natural gas.	This bill was a sort of empty gesture towards pro-natural-gas sentiments. The bill died in Pennsylvania committee in 2013.
Exp. of Natural Gas & Propane for Agriculture.	**This bill made funding available for natural gas infrastructure projects relating to agriculture in North Carolina in 2013.**
Conversion of vehicles to compressed natural gas; creating the County Fleet Vehicle Compressed Natural Gas Conversion Funding Act of 2014. Emergency.	This bill was never fully fleshed out, but had the potential to increase natural gas demand. The bill died in an Oklahoma committee in 2014.

Bill Title	Explanation
An act relating to the taxation of natural gas infrastructure	**A bill to revamp the way that natural gas facilities and transmission lines were taxed: all tax revenue would go to a Clean Energy Development Fund to help the areas around natural gas facilities. This bill died in a Vermont committee in 2014.**
Providing sales and use tax exemptions, in the form of a remittance of tax paid, to encourage coal-fired electric generation plants to convert to natural gas-fired plants or biomass energy facilities.	This Washington bill was first introduced in 2015 to encourage coal plants to switch to natural gas or biomass. The bill has seen majority support but was punted and reintroduced several times, where it was last seen in March 2016.
Relating to the recovery of certain natural gas distribution utility ratemaking proceeding expenses; adding provisions subject to a criminal penalty.	**A small tweak to the way gas utilities charge consumers in the state of Texas. This bill died in committee in 2015.**
An act prohibiting the storage or disposal of waste from hydraulic fracturing and natural gas and oil extraction activities.	This Connecticut bill would make fracking and other natural gas extraction more difficult. The bill was introduced in January 2017, and is pending further progress in committee.

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